

Grating size needed to protect adult Pacific lamprey in the Columbia River Basin

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EXECUTIVE SUMMARY

At hydropower projects in the lower Columbia River Basin, migrating adult Pacific lamprey *Lampetra tridentata* routinely pass through picket leads and diffuser gratings into areas where they can be delayed, injured, or killed. The objective of this project was to determine the gap sizes needed to exclude adult lamprey.

We conducted lamprey passage evaluations in the Adult Fish Facility at Bonneville Dam. We evaluated the ability of adult lamprey to pass through vertical gaps of 2.5, 2.2, 1.9, 1.6, or 1.3 cm in height. Vertical gaps were produced by placing a perforated divider in a large (1.8-m × 0.9-m × 0.6-m) flow-through tank and then raising the divider from the tank floor by placing appropriately sized spacers under its bottom edge. Mean length of the 242 lamprey used in these evaluations was 67.5 cm (SD = 4.2, range 53.0-79.0), mean weight was 494 g (SD = 85, range 282-800), and mean girth was 11.3 cm (SD = 0.8, range 9.2-13.7). All lamprey were able to volitionally pass through a 2.5-cm vertical gap, 47% passed through a 2.2-cm gap, and no lamprey passed through gap sizes of 1.9 cm or less.

We also conducted dewatering simulations using 50 additional lamprey. For these tests, a diffuser grating partition was positioned horizontally in the tank at a depth of 15 cm; completely separating the tank into upper and lower compartments. Ten lamprey were released in the upper part of the tank and the water was then lowered 30 cm in 3 min, stranding the lamprey on the grating and inducing them to pass through into the lower compartment. The groups of lamprey were tested with two grating sizes: 2.5 or 1.9 cm. The lamprey used in these experiments were comparable in size to those used in the vertical gap experiments: mean length was 67.5 cm (SD = 4.7, range 56.0-77.0), mean weight 481 g (SD = 88, range 284-684), and mean girth 11.0 cm (SD = 0.9, range 8.9-12.9). No lamprey passed through diffuser grating with 1.9-cm bar spacing, while 86% were able to pass through grating with 2.5-cm bar spacing.

Based on these results, and on comparisons to size ranges of lamprey collected after a year of freshwater residence, we concluded that a gap or bar spacing of 1.9 cm (3/4 in) is needed to exclude most adult Pacific lamprey in the Columbia River drainage. Using this information, the U.S. Army Corps of Engineers conducted a field test of the 1.9-cm grating at John Day Dam. No lamprey passed through the 1.9-cm grating they installed, further confirming our findings.

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INTRODUCTION

Lamprey management at manmade structures has become necessary at many facilities worldwide. In some areas, conservation of native lamprey is of concern, and lamprey must be protected from entrainment in wastewater or irrigation diversion systems along the migration route, as well as in turbine intakes and fish guidance screens at hydropower dams (Dauble et al. 2006). Conversely, control of non-indigenous lamprey may require installation of barriers to prevent lamprey from colonizing new areas (Lavis et al. 2003). In addition, both native and non-indigenous lampreys may be targeted for trapping operations. In all these cases, information on the bar spacing that will exclude lamprey at screens, trash racks, picket leads, wire mesh, or diffuser gratings is needed (Moursund et al. 2001, 2002, 2003).

In the Columbia River Basin, Pacific lamprey *Lampetra tridentata* are of conservation concern (Close et al. 2002). Lamprey populations have diminished, and as a result, tribal and commercial harvest of lamprey has been curtailed. Moreover, the Pacific lamprey and three other lamprey species have been nominated for listing under the Endangered Species Act, due to concerns about their population status (Moser and Close 2003). Pacific lamprey are anadromous, participating in migrations to freshwater spawning areas that can exceed 700 km. Protection of the adults during their migration past Columbia River hydropower dams has been identified as a priority for restoration of lamprey populations (CRBLTW 2004).

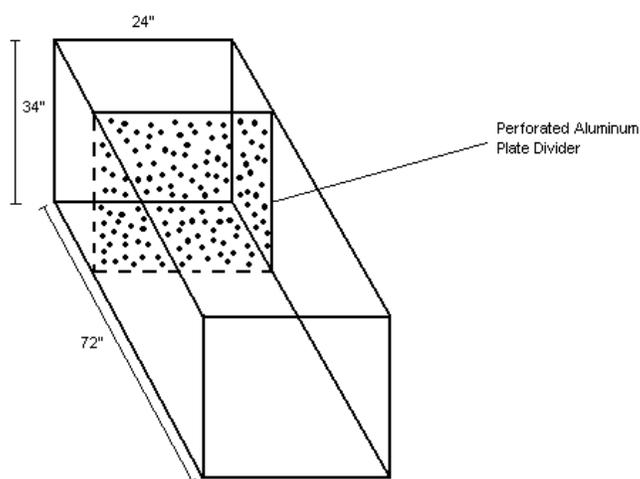
Adult Pacific lamprey can suffer both delay and mortality during passage through the fishway systems at Columbia River hydropower dams. Fishways at these dams were originally constructed to promote adult salmonid passage. Consequently, many of the dam structures and operations do not optimize lamprey passage and survival. For example, picket leads and diffuser grating at these dams are sized to exclude salmonids from dead-end channels, pumps, and other sources of mortality. However, lamprey can pass through some of these structures and have been subject to both delayed migration (due to entry into channels that lead nowhere) and mortality (during de-watering operations for fishway maintenance). The objective of this study was to determine the gap sizes that will exclude migrating adult Pacific lamprey in the Columbia River Basin.

METHODS

Lamprey were collected and experiments conducted at Bonneville Dam (Columbia River km 235), the first mainstem hydropower dam that adult lamprey encounter during their upstream migration. Lamprey were captured in a trap that was deployed each night in a Bonneville Dam fishway (see Moser et al. 2002 for details of trap operation). Each morning, experiments were conducted in the Adult Fish Facility using lamprey collected the previous night. Lamprey were anesthetized using 50 ppm eugenol, weighed (nearest g), and measured (nearest cm total length). In addition, lamprey circumference (girth) at the anterior edge of the first dorsal fin was measured (nearest mm). Two types of experiments were conducted: vertical gap passage tests (July-August 2005), and horizontal dewatering simulations (July 2006).

Vertical Gap Experiments

These experiments were designed to determine the minimum vertical gap that lamprey could pass through. A large (1.8-m × 0.9-m × 0.6-m) flow-through tank was



filled with ambient Columbia river water. This tank was divided into two unequal compartments with a divider made of perforated aluminum plate (0.6 cm perforations), which slid snugly along guides in the tank wall (Figure 1). A vertical gap (2.5, 2.2, 1.9, 1.6, or 1.3 cm in height) was produced at the bottom of the divider by placing an appropriately sized spacer under the bottom edge of the plate.

Figure 1. Experimental apparatus used to test lamprey ability to pass through a vertical gap. A vertical gap of 2.5, 2.2, 1.9, 1.6, or 1.3 cm was created by placing a spacer of the appropriate size under the perforated partition.

Each morning, lamprey trapped the previous night were placed into the smaller tank compartment and encouraged to pass under the divider and into the larger compartment. After approximately 15 min, the spacers were removed, and the divider was lowered to the tank bottom to isolate lamprey that had successfully passed through. Individuals of both groups were then anaesthetized, measured, and released. Three replicates of each of the five vertical gap treatments were made at approximately 1-week intervals. Hierarchical analysis of variance was used to determine whether there were significant differences in lamprey size among dates and treatment groups.

Horizontal Dewatering Simulations

These experiments simulated conditions that lamprey would experience during dewatering operations for fishway maintenance. As water in the fishways is drained, lamprey can pass through diffuser grates in the floor of the fishways and enter areas below the grating. Traditional diffuser grating material used at Columbia River hydropower dams is a rectangular metal grid that is 4.4 cm deep and has 2.5×9.2 cm openings (Figure 2). We tested this material (2.5 cm grating) and another commercially-available diffuser grating that had 1.9×9.2 cm openings (1.9 cm grating).

For these tests, a large ($1.8 \times 0.9 \times 0.6$ m) flow-through tank was filled with ambient Columbia River water. A horizontal grate was installed at a depth of 15 cm to completely separate the tank into upper and lower compartments



Figure 2. Photograph of traditional 2.5-cm diffuser grating material.

(Figure 3). The choice of grating size was random. Ten lamprey were placed in the tank above the grate and allowed to acclimate for 5 min. Water in the tank was then lowered 30 cm in 3 min, so that lamprey were stranded on the grate for a maximum of approximately 2 min and induced to pass down into the lower compartment (Figure 4).

The experiment was then repeated with the same lamprey using the other grating size. Lamprey that passed down through the grate and into the tank were scored, and all lamprey were anesthetized, measured, and released. A *t*-test was used to determine whether there were significant differences in size between lamprey that passed through and those that did not for each grating size.

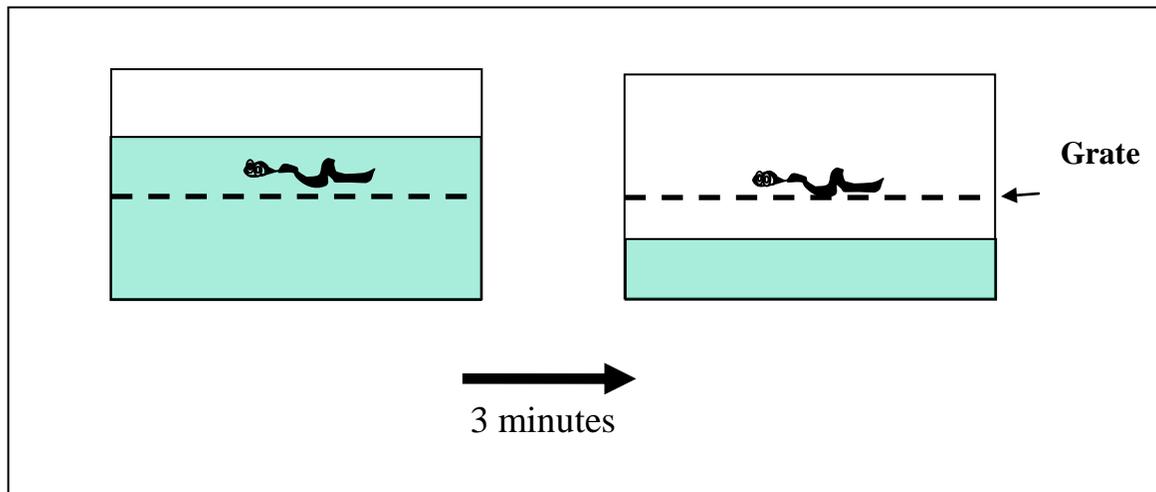


Figure 3. Cartoon of horizontal dewatering simulation as viewed from the side. A grate (either 2.5- or 1.9-cm bar spacing) was installed in a tank at a depth of 15 cm and 10 lamprey were released above it. The water level was then dropped by 30 cm over the course of 3 min, so that the lamprey were stranded on the grate for 2 min and induced to pass vertically through it.



Figure 4. Adult Pacific lamprey stranded on diffuser grating during horizontal dewatering simulation.

RESULTS

Vertical Gap Experiments

Due to the variation in daily catch rates, the number of lamprey used for each treatment was not constant (Table 1). There were no significant differences in fish length ($F = 1.05$, $df = 15$, $P = 0.41$), weight ($F = 0.46$, $df = 15$, $P = 0.96$), or girth ($F = 0.42$, $df = 15$, $P = 0.97$) among treatments or test dates. The mean length of lamprey tested was 67.5 cm (SD = 4.2, range = 53.0 -79.0). Mean weight was 494 g (SD = 85, range = 282-800), and mean girth was 11.3 cm (SD = 0.8, range = 9.2-13.7).

All lamprey were able to pass through the 2.5-cm gap, 47% were able to pass through the 2.2-cm gap, and no lamprey were able to pass through gap sizes of 1.9-cm or less (Table 1). For the 2.2-cm treatment group, there was no significant difference in length ($t = 0.49$, $df = 85$, $P = 0.62$), weight ($t = 0.44$, $df = 85$, $P = 0.66$), or girth ($t = 0.52$, $df = 85$, $P = 0.60$) between fish that passed through and those that did not, and size frequency distributions of the two groups were similar (Figure 5).

Table 1. The mean, standard deviation, and range of lamprey length, weight, and girth for each vertical gap treatment. The percentage of lamprey that were able to pass through each treatment is also given.

Vertical gap size	n		Length (cm)	Weight (g)	Girth (cm)	Passage (%)
2.5 cm	53	mean (SD)	67.5 (4.3)	489.7 (76.5)	11.4 (0.8)	100
		range	53.0-76.0	282.0-658.0	9.5-13.2	
2.2 cm	87	mean (SD)	67.5 (4.1)	496.7 (87.7)	11.3 (0.8)	47
		range	57.0-78.0	308.0-800.0	9.5-13.7	
1.9 cm	23	mean (SD)	67.5 (3.8)	492.8 (83.7)	11.3 (0.8)	0
		range	58.0-73.0	326.0-678.0	9.3-12.8	
1.6 cm	33	mean (SD)	68.4 (4.8)	506.0 (97.4)	11.4 (0.8)	0
		range	57.0-79.0	308.0-760.0	9.6-13.3	
1.3 cm	46	mean (SD)	67.0 (4.0)	485.6 (80.4)	11.3 (0.8)	0
		range	58.0-74.5	318.0-638.0	9.2-12.5	

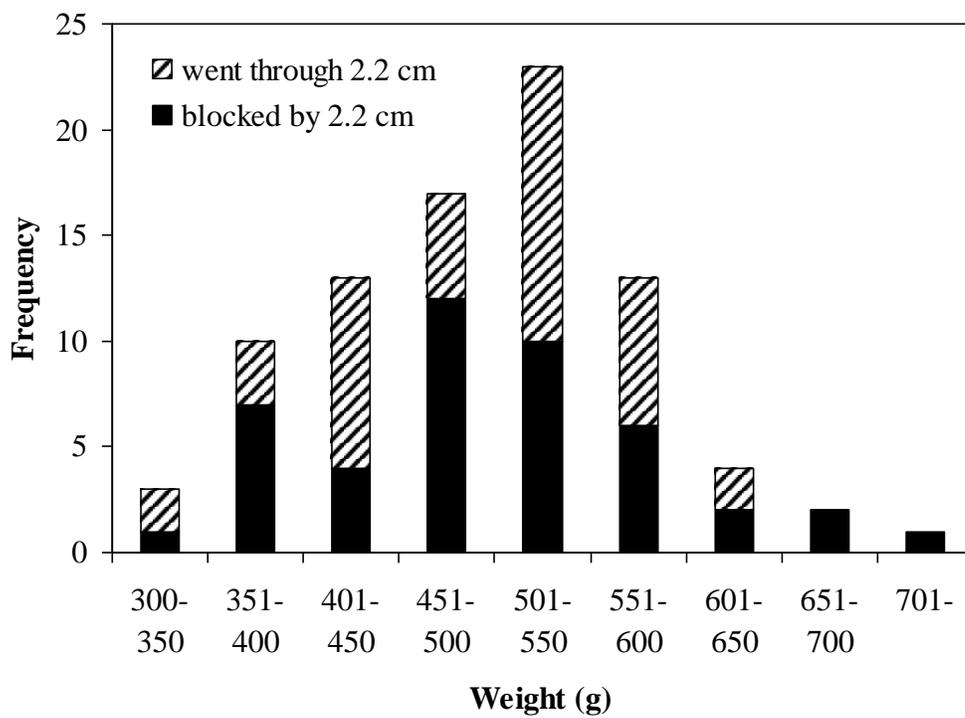
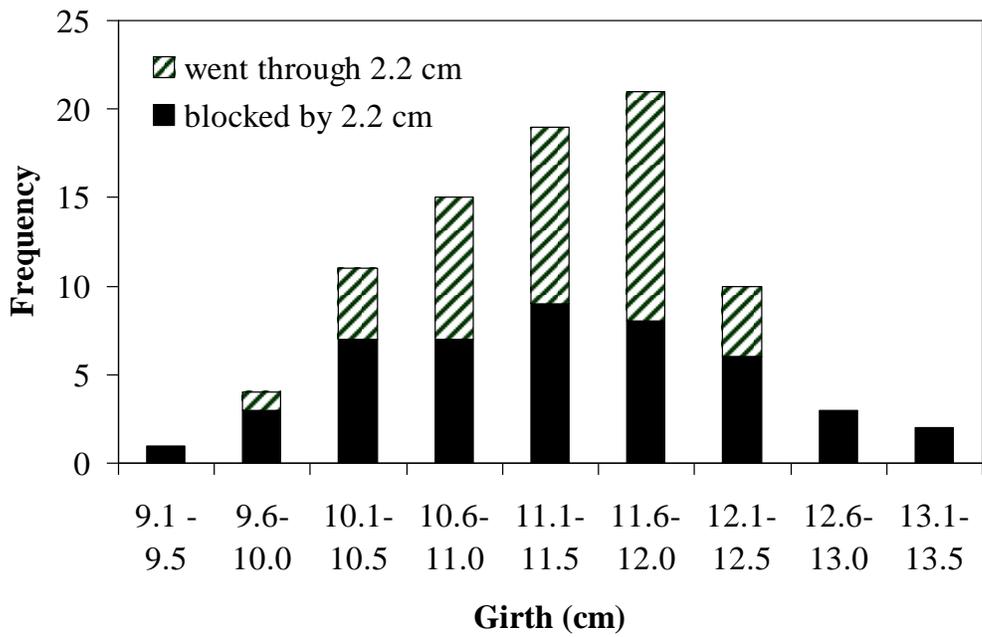


Figure 5. Size frequencies (girth in top panel and weight in bottom panel) of adult Pacific lamprey that were able to pass through a 2.2-cm vertical gap (hatched bars) and those that were blocked by a gap of this size (solid bars).

Horizontal Dewatering Simulations

The 50 lamprey used in these experiments were comparable in size to those used in the vertical gap experiments: mean length was 67.5 cm (SD = 4.7, range = 56.0-77.0), mean weight 481 g (SD = 88, range 284-684), and mean girth 11.0 cm (SD = 0.9, range = 8.9-12.9). None of these lamprey were able to pass down through the 1.9-cm grating. In contrast, all but 7 (86%) were able to pass down through the 2.5-cm grating. The 7 lamprey that were stranded on the 2.5-cm grating were at the upper end of the size distribution (Figure 6) and were significantly larger than those that passed through in terms of length ($t = 2.42$, $df = 48$, $P = 0.02$), weight ($t = 4.38$, $df = 48$, $P < 0.0001$), and girth ($t = 4.50$, $df = 48$, $P < 0.0001$).

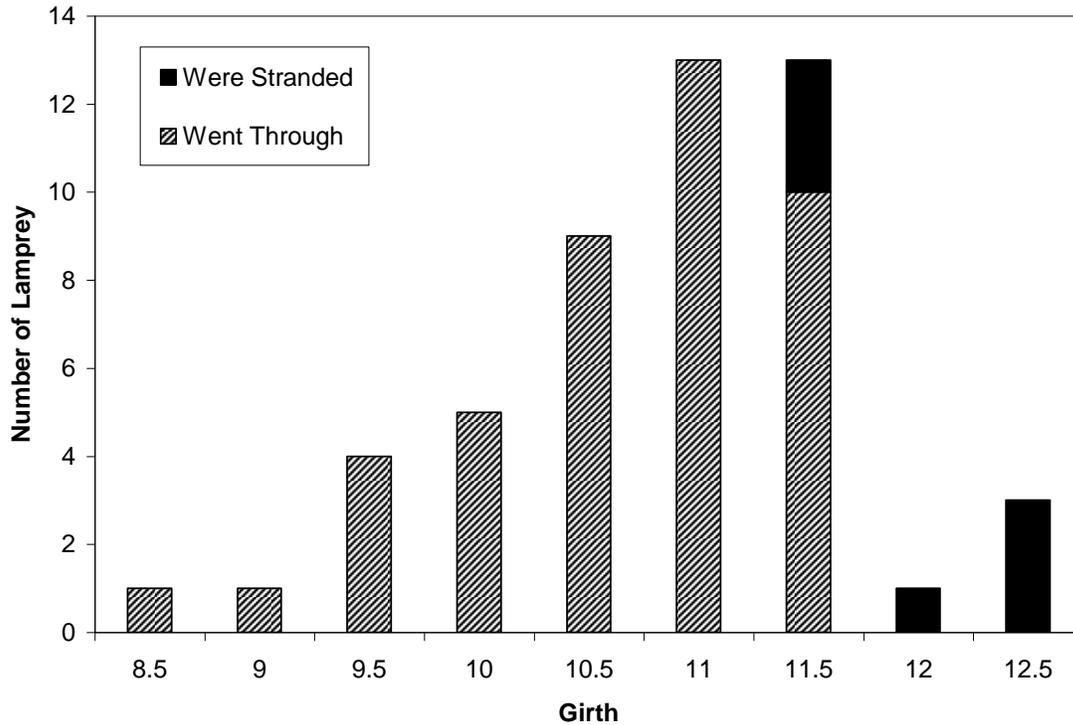


Figure 6. Frequency histogram of the lamprey girth (cm) recorded for fish that passed through the 2.5-cm bar spacing (hatched bars) and those that were stranded on it (solid bars) during horizontal dewatering simulations.

DISCUSSION

Both the vertical and horizontal test scenarios indicated that the entire size range of lamprey collected in the lower Columbia River can be excluded by using a gap size or bar spacing of 1.9-cm or less. Following these evaluations, the U.S. Army Corps of Engineers tested the results at Pool 16 of the John Day Dam south fishway (Columbia River km 347). This section of the fishway had historically been an area where lamprey died after passing through the existing 2.5-cm grating during dewatering operations. The 2.5-cm grating was replaced with 1.9-cm grating in winter 2005. During dewatering operations in winter 2006, no lamprey were able to pass through the new grating. Thus, a first, simple field trial confirmed the results of our experiments.

Even though we tested lamprey only at the start of their freshwater residence, the size range tested was probably representative of most adult Pacific lamprey that would encounter fish passage facilities in the Columbia River Basin. Lamprey, like those we caught in July and August, spawn the following spring (nearly a year later). During this time in freshwater, adult Pacific lamprey do not feed, and laboratory studies indicate that they shrink at rates of 0.16 to 0.40 g d⁻¹ (Whyte et al. 1993; M. Mesa, U.S. Geological Survey, unpublished data). The smallest lamprey we tested was 53 cm long, weighed 282 g, and measured 9.2 cm in girth. This lamprey was smaller than those collected during winter dewatering operations at John Day Dam in December 2005 (range in girth = 9.5-11.2 cm; D. Cummings, University of Idaho, unpublished data) and smaller than most lamprey measured after overwintering on endogenous stores (range = 53-75 cm TL, 260-578 g; A. Jackson, Confederated Tribes of the Umatilla Indian Reservation, unpublished data). However, it is possible that the very smallest end of the Pacific lamprey size frequency distribution may have been missed in our testing.

The range of Pacific lamprey sizes we tested was not representative of most other parasitic lamprey species. Our smallest lamprey was larger than the average adult river lamprey *L. ayresi* from the Fraser River in British Columbia (Beamish 1980), and also larger than the average non-indigenous sea lamprey *Petromyzon marinus* in the Great Lakes of North America (Johnson and Anderson 1980). Other anadromous lampreys of the northern hemisphere are typically even smaller. It is not clear that measurements of length, weight, or girth can be scaled to determine gap sizes that would exclude these species. In our experiments, lamprey that passed through and those that were blocked by a 2.2-cm vertical gap had similar weight and girth.

Perhaps weight and girth at the first dorsal insertion do not capture the dimension that limits lamprey passage through a gap. As lamprey shrink, the branchial basket appears to remain constant in size when compared to other body parts (D. Cummings, University of Idaho, personal communication). The girth of this structure is therefore most likely to limit lamprey passage, as it is less flexible and more constant in size than other parts of the body.

Lamprey movement through a gap did not seem to be affected by the gap orientation. Lamprey moved nearly as easily through a vertically oriented 2.5-cm gap as they did through a horizontal one. This is probably due to the lamprey's tubular shape and generally compressible body. The 2.5-cm gap represents approximately 70% of the mean lamprey diameter and less than 60% of the largest lamprey diameter. When stranded on the horizontal grating, lamprey often opted to pass through tail first. After backing partially through the gap, they were able to flex the tail and thereby lever the rest of the body through. The use of the tail to attempt passage through a small opening has also been observed in juvenile Pacific lamprey (Moursund et al. 2000). When in water during the vertical gap trials, adult lamprey typically approached and passed through the gap headfirst. This tendency to move head first was also observed in experiments where lamprey encountered a vertically oriented set of bars or pickets (D. Ogden, National Marine Fisheries Service, personal communication).

In conclusion, the results of these experiments indicated that by replacing traditional 2.5-cm (1-in) diffuser grating with the 1.9-cm (3/4-in) grating, nearly all adult Pacific lamprey in the lower Columbia River could be excluded from areas where they could be delayed, injured, or killed. Reducing the bar spacing of trash racks, picketed leads, and diffuser gratings could thereby confer protection to this species in a variety of applications.

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